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PROTECTION OF MOORING BUOYS -- PART X. RESULTS OF NINTH RATING INSPECTION

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PROTECTION OF MOORING BUOYS — PART X. RESULTS OF NINTH RATING INSPECTION

Technical Report R-542

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by

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ABSTRACT

This is the tenth of a series of reports on the protection of mooring buoys. Thirteen buoys were given their ninth rating (after a maximum of 5 years exposure) for extent of coating deterioration, corrosion of steel, and fouling. Two other buoys had previously been removed from the test program because of advanced deterioration. The coating systems on three of the buoys were in good condition, while those on nine others showed varying degrees of moderate deterioration, and one was in such poor condition that it was also removed from the test program. Two sets of steel panels coated with the different systems used on the buoys were given their eighth rating inspection after 4 years of exposure. One set was exposed in San Diego Bay and the other in Port Hueneme Harbor. The condition of the coatings on both sets of panels was generally better than that of the buoy coating, but there was a general correlation between the conditions of the two test groups. On buoys coated with antifouling paints, no detectable antifouling property remained after 20 months, but on both sets of test panels, two antifouling coatings containing copper oxide were still appreciably reducing fouling after 4 years.

Patches of underwater-curing epoxy applied to buoys where localized damage to the coating had been caused by abrasion were in good condition. Some patches had been providing protection for 4 years.

Three of the buoys were cathodically protected with zinc anodes. The underwater portions of these buoys were receiving protection from corrosion 33 months after anode installation.

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The Laboratory invites comment on this report, particularly on the results obtained by those who have applied the information.

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INTRODUCTION

The Naval Facilities Engineering Command assigned the Naval Civil Engineering Laboratory the task of finding or developing better methods for protecting Fleet mooring buoys from corrosion. The assignment included investigation of both protective coatings and cathodic protection.

A field-test program was initiated in San Diego with 15 peg-top riser-chain mooring buoys (Mark I or Mark II). Thirteen different coating systems were used, and a cathodic protection system was installed on one buoy of each of three pairs used in this part of the test program. The same thirteen coating systems were also applied to two sets of test panels, one exposed in San Diego Bay and the other in Port Hueneme Harbor. The results of the program are being published in a series. Technical Report R-246,[1] the first in the series, described the application of protective coatings and the installation of a cathodic-protection system. Subsequent reports[2-9] described the condition of the buoys from the first through the eighth rating inspections and the condition of the panels through their seventh rating inspection. This report describes the condition of the buoys at the time of their ninth rating inspection (up to 5 years exposure) and the condition of the panels after 4 years of exposure.

SERVICE CONDITIONS

For the test, 15 mooring buoys were placed in an area of North San Diego Bay that received heavy service from the Fleet. Some of the buoys were badly damaged by overriding vessels and by the abrasion of mooring lines and securing assemblies. Because it was necessary to place the test buoys in service a few at a time, and because there were long delays in obtaining acceptable specification coatings, preparation and placement of all the buoys required a long time.

One set of 13 panels was suspended from a pier in San Diego Bay and the other from a pier in Port Hueneme Harbor. A portion of each panel was continuously submerged, another portion was intermittently submerged by rising tide, and a third portion was continuously exposed to the atmosphere. The panels were not exposed to their harbor environments at the same time as the buoys; they were kept in storage until all of them had been coated. All the panels were then placed in test position at the same time, rather than over a 6-month period as were the buoys. At the time of their ninth rating (described herein) they had been exposed for 4 years.

INSPECTION PROCEDURE

Each of the test mooring buoys was inspected after it had been lifted onto the deck of a floating crane. The amount of fouling was determined, the types of organisms were recorded, and fouling damage to the coating was noted. After the fouling was examined, the cone and splash zone of each buoy were washed with a high-pressure stream of seawater to remove the fouling and expose coating damage. Two independent ratings of the condition of each buoy and its protective coating system were made in the atmospheric, splash, and submerged zones.

Electrical potential measurements were made on buoys with and without cathodic protection to determine the amount of additional potential produced on cathodically protected buoys. The coating deterioration and corrosion damage of the three cathodically protected buoys were compared to those of the control buoys.

Two independent ratings were also made of the condition of the coating systems on the steel test panels exposed in San Diego Bay and Port Hueneme Harbor. Fouling organisms were carefully removed from one side of each test panel with a wooden scraper and a stiff bristle brush before the coating condition in the fouled area was rated.

RATING CRITERIA

So far as possible, the methods of rating the coatings on buoys and test panels were those published by the American Society for Testing and Materials.[10] These published methods define the conditions rated and give photographic reference standards. Thus, chalking, blistering, checking, cracking, flaking, erosion, and rusting were rated from 0 to 10 by ASTM methods D-659-44, D-714-56, D-660-44, D-661-44, D-772-47, D-662-44, and D-610-43, respectively. A rating of 10 usually describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. Blistering frequency was rated as none (N), few (F), medium (M), medium dense (MD), or dense (D). Surface areas covered by fouling (plant, animal, or a combination) were rated on a linear scale from 0 (100% covered) to 10 (0% covered). Color of the topcoat on the buoys was also rated from 0 to 10; 10 indicates pure white with no yellowing or other discoloration (except rust streaks from uncoated bolts), and 0 indicates a color unacceptable to the U. S. Coast Guard.

Frequency of use of buoys by the Fleet was rated as light (0 to 2 days per week), medium (2 to 4 days per week), or heavy (4 to 7 days per week). Some of the buoys provide bow and stern mooring only, and the rest provide either bow and stern or free-swinging moorings.

The overall condition of each buoy and its coating system was rated as excellent (in essentially the same condition as when first placed in service); good (very minor deterioration); fair (a significant amount of coating deterioration or rusting, but still in serviceable condition); and [illegible] coating deterioration and rusting serious enough to lead to an early removal [illegible]ice).

The coating system on each test panel was given an overall rating from 0 (minimum protection) to 10 (maximum protection), depending upon both the condition of the entire coating system and the protection afforded to the steel. It was much easier to rate the overall coating conditions on the panels than on the buoys, because the panels were not abraded as were the buoys during mooring service.

CONDITION OF BUOY COATINGS

General

Table 1 describes each coating system. The overall ratings and lengths of service of buoy coatings are summarized in Table 2. The sources of the coatings are listed in References 2 through 4, are proprietary, and are available only to U. S. Government agencies and their contractors. Ratings of specific conditions of coated test buoys are given in Appendix A.

The fouling on all test buoys was generally similar both in type and amount (Figure 1), with slightly differing amounts occurring in different test areas. Green algae and barnacles were most conspicuous in the splash zone. Tunicates and barnacles were most conspicuous in the submerged zone, and mussels, bryozoa, hydroids, and tube worms were usually present to a lesser extent.

The Mark I test buoys usually had marine borer damage on their lower, untreated wooden fenders (Figure 2). The lower, creosoted fenders of the larger Mark II buoys were almost always completely out of the water and suffered no marine borer attack.

Coating System 1: Urethane

The condition of the System 1 buoy (Figure 3) had deteriorated slightly since the previous rating inspection, and there was somewhat greater rusting in the atmospheric and splash zones. Much of this, however, was either of the pinpoint type (Figure 4) or had been caused by impact or abrasion. The pinpoint rusting on the buoy side was initiated by small blisters previously noted there.

The many patches of underwater-curing epoxy,[11] most of which had been applied 4 years earlier to underwater areas damaged by the impact of moored vessels, were still adhering tightly to the underlying steel and providing good protection from corrosion. Some of these patches had lifted edges where they bonded poorly to fouling or weathered coating. The epoxy patches have extended significantly the service life of the buoy.

There was moderate galvanic corrosion of the bolts securing the lower lateral fender in place and moderate marine borer damage to this fender.

Table 1. System Description and Coating Thickness

System		Primer			Additional Coats			Total Thickness (mils)
Number	Description	Type	Coats (No.)	Thickness (mils)	Type	Coats (No.)	Thickness (mils)	
1	Urethane	Urethane	1	2	Urethane	3	8	10
2	Epoxy	Epoxy	1	4-5	Epoxy	1	4	8-9
					Epoxy	1	3	11-12
					Antifouling	1	4	15-16
3	Epoxy-Polyester	Epoxy	1	4-5	Polyester	2	5-6	9-11
					Antifouling	1	4	13-15
4	Epoxy-Coal Tar Epoxy	Epoxy	1	4	Coal Tar Epoxy	1	4-5	8-9
					Epoxy	1	4	12-13
					Epoxy	1	4	16-17
5	Coal Tar Epoxy-Phenolic	Coal Tar Epoxy	1	5	Phenolic	1	4-6	9-11
					Phenolic	1	6-7	15-18
6 & 6C	Phenolic Mastic	Mica-filled Phenolic	1	10-11	Phenolic Mastic	1	8-9	18-20
7C	Phenolic	Wash Primer	1	½	Phenolic	1	2-3	7-8
		Phenolic	2	4½	Antifouling	1	3	8
8	Phenolic-Alkyd	Wash Primer	1	½	Alkyd	1	2-3	7-8
		Phenolic	2	4½	Antifouling	1	3	8
9	Vinyl	Wash Primer	1	½	Vinyl-Alkyd	3	4	11-12
		Vinyl	4	6½-7½	Antifouling	2	4	11-12
10	High-Body Vinyl	Vinyl	1	2	Vinyl	2	5-6	7-8
					Vinyl	1	2	9-10
11	Vinyl Mastic	Vinyl Phenolic	1	1-2	Vinyl Mastic	2	12-13	13-15
12	Inorganic Zinc Silicate-Vinyl Mastic	Inorganic Zinc	1	4	Vinyl Mastic	1	5-6	10-12
		Silicate-Vinyl Phenolic	1	1-2				
13 & 13C	Saran (Formula 113/54)	—	—	—	Saran	8	8	8

Table 2. Overall Rating and Length of Service for Coated Buoys

Coating System		Length of Service (months)	Overall Rating
Number	Description		
1	Urethane	56	fair
2	Epoxy	54	good
3	Epoxy-Polyester	54	fair
4	Epoxy-Coal Tar Epoxy	56	good-fair
5	Coal Tar Epoxy-Phenolic	54	fair
6	Phenolic Mastic	54	good-fair
6C	Phenolic Mastic	54	good
7C	Phenolic	49	good-fair
8	Phenolic-Alkyd	49	good-fair
9	Vinyl	50	good-fair
10	High-Body Vinyl	—	removed from test
11	Vinyl Mastic	—	removed from test
12	Inorganic Zinc Silicate-Vinyl Mastic	56	poor
13	Saran	54	good-fair
13C	Saran	55	good

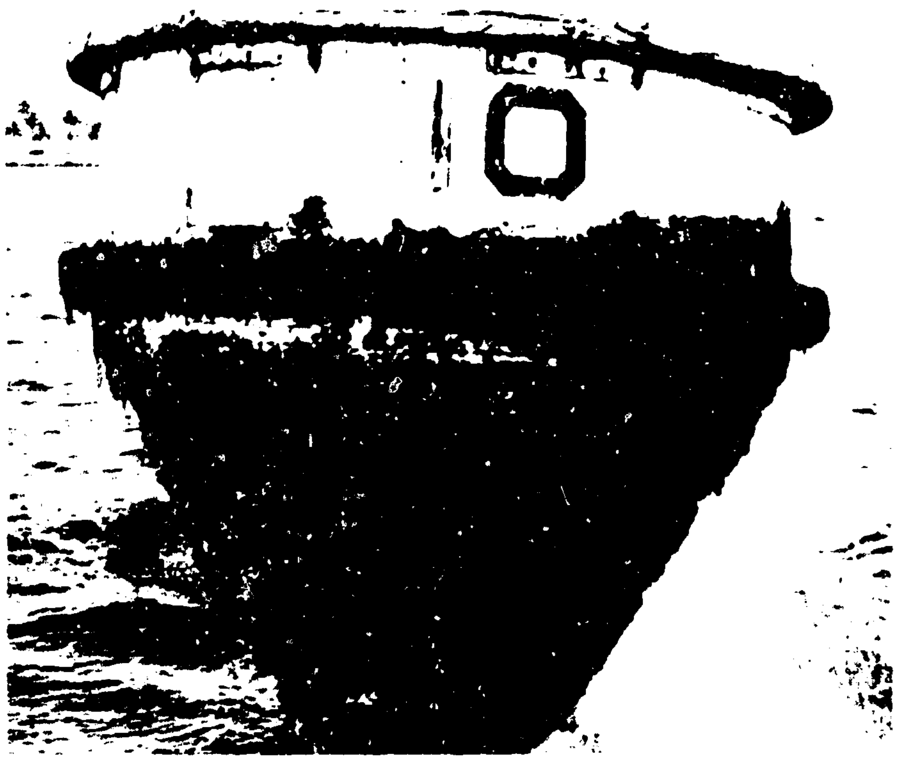

Figure 1. Typical fouling as seen on System 5 buoy.

Figure 2. Typical untreated wooden fender with marine borer damage.

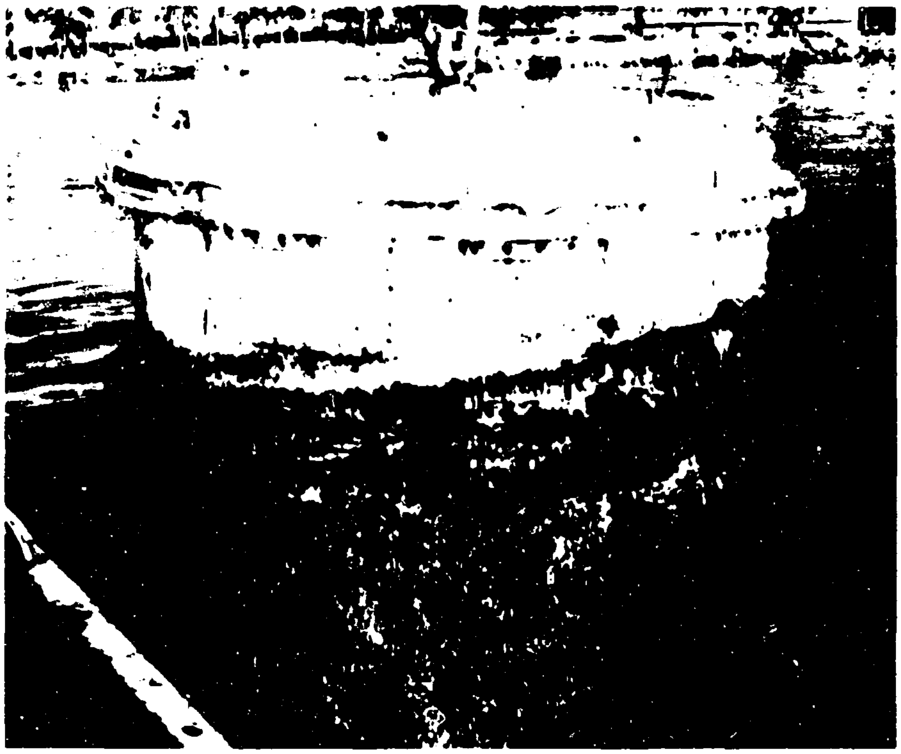

Figure 3. System 1 buoy before removal of fouling.

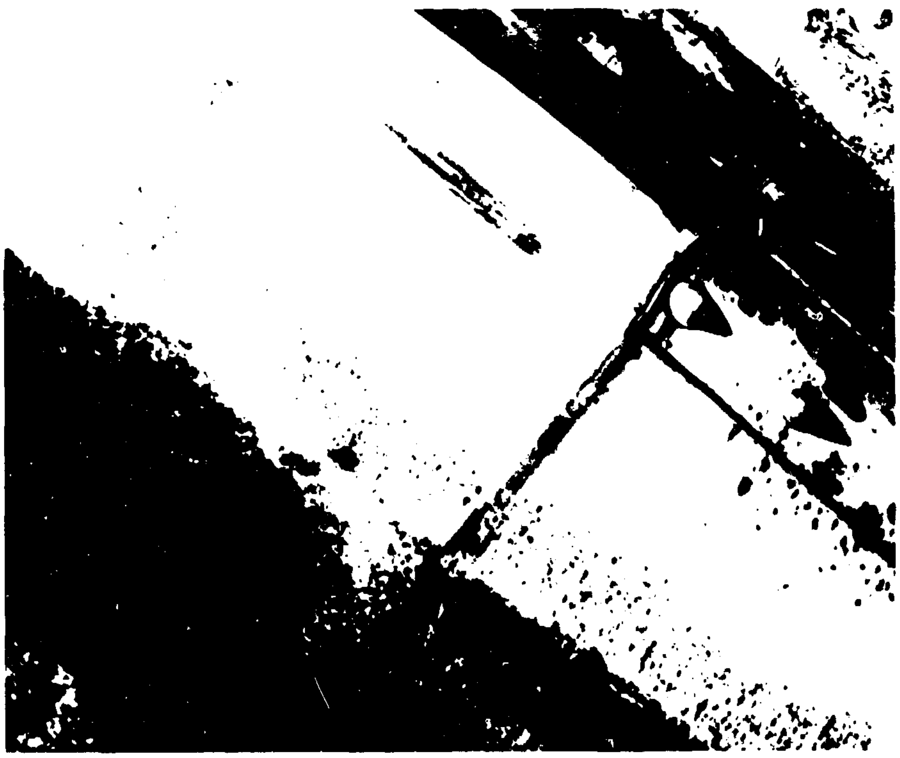

Figure 4. Pinpoint rusting on side of System 1 buoy.

Coating System 2: Epoxy

The condition of the System 2 buoy was essentially unchanged since the last inspection. The two areas where impact damage to the coating had been patched with underwater-curing epoxy 1-1/2 years earlier[7] were receiving full protection from these patches. There was very little rusting on this buoy except that caused by abrasion. There was some galvanic corrosion on bolts and rivet heads in the submerged zone and extensive marine borer damage to the lower fender.

Coating System 3: Epoxy-Polyester

The condition of the System 3 buoy had changed only slightly since the last inspection. The epoxy primer exposed in the submerged zone, where much of the polyester topcoating had previously delaminated, was continuing to protect the underlying steel. The rusting in all three zones was related to abrasion damage. There was an area of coating on the underwater portion of the buoy that had suffered abrasion damage (Figure 5) since the last inspection. This was repaired with a patch of underwater-curing epoxy. As with the previous Mark I buoy (System 2), there was galvanic corrosion on a few abraded rivet heads in the submerged zone and marine borer damage to the lower lateral fender.

Coating System 4: Epoxy-Coal Tar Epoxy

The condition of the System 4 buoy was virtually unchanged since the last inspection. The previously noted delamination of the topcoat and seal coat in the submerged zone had not advanced significantly, and the underlying epoxy primer and coal tar epoxy were providing good protection to the steel. The cone of the buoy had suffered slight abrasion damage since the previous inspection and the orange primer was exposed in a few places. Elsewhere the coating system was performing well, with the slight rusting noted related to abrasion damage.

Coating System 5: Coal Tar Epoxy-Phenolic

The condition of the System 5 buoy was virtually unchanged since the last inspection. Most of the coating damage, notably that on the buoy top, was related to abrasion damage. There was galvanic corrosion of some abraded rivet heads in the submerged zone and extensive marine borer damage to the lower lateral fender.

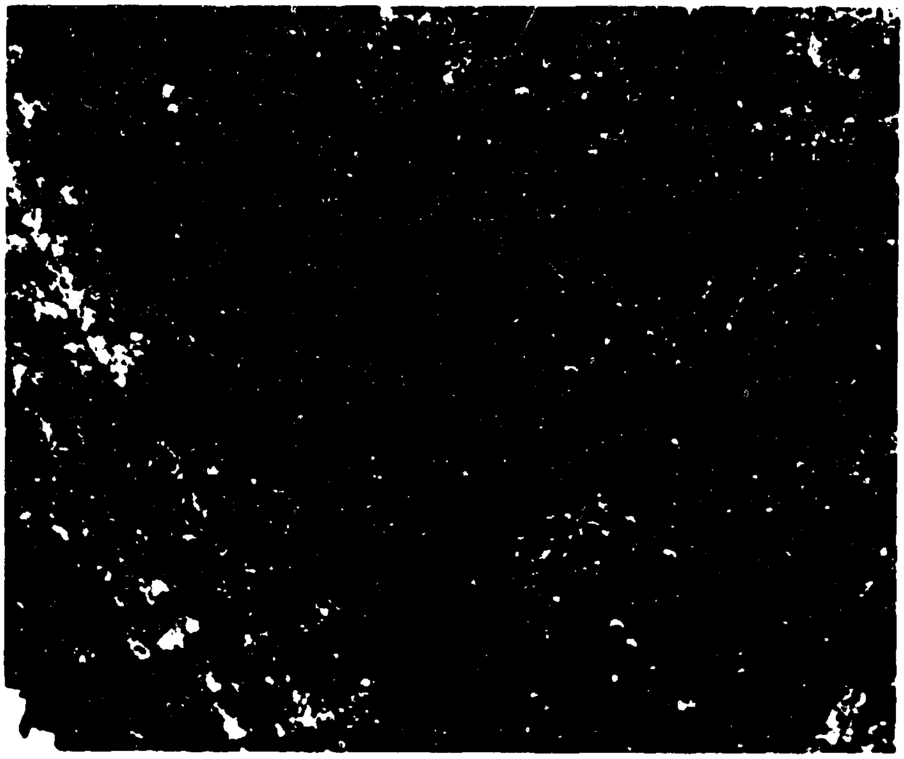

Figure 5. Cone of System 3 buoy showing abrasion damage to coating.

Coating Systems 6 and 6C: Phenolic Mastic

Systems 6 and 6C were identical, but the 6C coating was applied to a cathodically protected buoy. The condition of both buoys was virtually unchanged since the last inspection. The deterioration on each was largely the result of abrasion damage (see Figure 6). The better condition of the System 6C buoy is a result of the cathodic protection and the heavier fendering. The lower lateral fender on the System 6 buoy had extensive marine borer damage.

Coating System 7C: Phenolic

The condition of the System 7C buoy was virtually unchanged since the last inspection. The erosion of the antifouling coating on the underwater portion of the buoy was probably aggravated by barnacle attachment, since the antifouling coating had long since lost its toxicity to fouling organisms. The cathodic protection system on this buoy was still very effective in mitigating rusting where bare steel was exposed underwater. Most of the slight coating damage in the atmospheric and splash zones had been caused by abrasion.

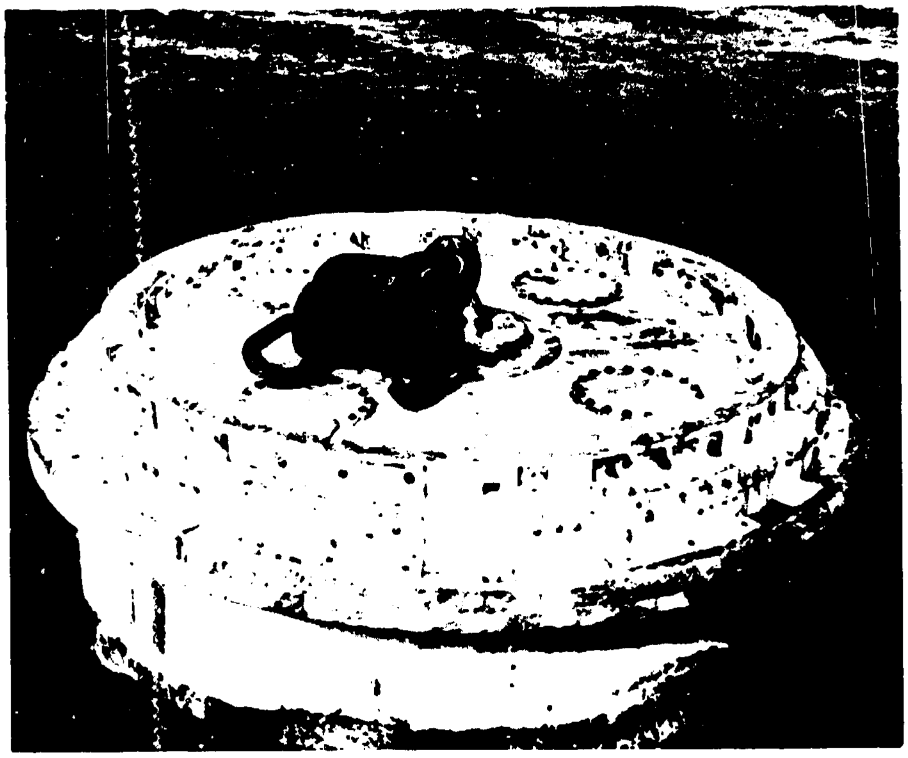

Figure 6. Abrasion damage on System 6 buoy.

Coating System 8: Phenolic-Alkyd

The condition of the System 8 buoy was virtually unchanged since the last inspection. The submerged portion of this buoy had the identical coating system used on the System 7C buoy, and consequently, the condition of the coating system in this area on both of these buoys was quite similar. There was, however, more rusting on the underwater portion of the System 8 buoy, since it did not receive cathodic protection. There was also evidence of a slight barnacle damage to the coating underwater. Rusting on the side of the buoy was either of the pinpoint variety or had been caused by abrasion.

Coating System 9: Vinyl

The condition of the System 9 buoy had changed very little since the last inspection. Several small areas of peeled coating on the buoy side, probably initiated by impact of a vessel, had been noticed and patched with underwater-curing epoxy during the last three inspections. The epoxy patches were all in good condition and were providing protection to the steel. An area of damaged coating adjacent to a flange on the side of the buoy (Figure 7) was noted at the present inspection. This was also cleaned and patched with underwater-curing epoxy in the manner previously used. The few areas of rusting in all three zones were related to abrasion damage. The type and amount of fouling on this buoy were similar to those on test buoys without an antifouling coating. There was galvanic corrosion on some of the bolts securing the lower lateral fender in place and extensive marine borer damage to this fender.

Coating System 10: High-Body Vinyl

Because of advanced corrosion, the System 10 buoy had been removed from the test program after 35 months of service.

Coating System 11: Vinyl Mastic

Because of advanced corrosion, the System 11 buoy had been removed from the test program after 19 months of service.

Figure 7. Side of System 9 buoy showing damaged wooden fender and damaged coating above lower right flange.

Coating System 12: Inorganic Zinc Silicate-Vinyl Mastic

The System 12 buoy had undergone further deterioration since the last inspection, and the underwater portion was in such poor condition (Figure 8) that the buoy was removed from the test program. The side and top of the buoy are still in good condition, but underwater there was extensive blistering and delamination of the vinyl mastic topcoating. The gradual loss of zinc from the exposed primer has permitted extensive rusting and pitting.

Coating Systems 13 and 13C: Saran

Systems 13 and 13C were identical, but System 13C was applied to a cathodically protected buoy. The System 13 buoy has remained in the mooring yard since the previous inspection because of problems associated with installing a new lighting system on the buoy.

The condition of the coating on both buoys was virtually unchanged since the last inspection. The slight rusting was either of the pinpoint variety or had been caused by abrasion. The System 13C buoy was receiving usage at the time of the inspection and it was necessary to inspect the buoy with a destroyer secured to it (Figure 9). The cathodic protection system was quite effective in mitigating corrosion on the underwater portion of the System 13C buoy.

CONDITION OF PANEL COATINGS

The coating system of each panel is rated in Table 3, and the ratings of the specific properties are given in Appendix B. There continues to be a distinct difference in the type of fouling at the two panel-testing sites. While barnacles are conspicuous at both locations, they form on the tidal zone of all San Diego panels without an antifouling paint a heavy crust that probably affords significant protection to the panels. Mussels and bryozoa are much more numerous and larger at Port Hueneme. Conversely, tunicates and sponges are most conspicuous at San Diego, but virtually absent at Port Hueneme.

Coating System 1: Urethane

Both urethane-coated panels were little changed since the last inspection. The slight coating deterioration on the San Diego panels consisted of edge damage, a few pinholes, and slight barnacle damage. The small blisters and delamination of topcoat on one side of the Port Hueneme panel previously noted[8, 9] had not increased appreciably.

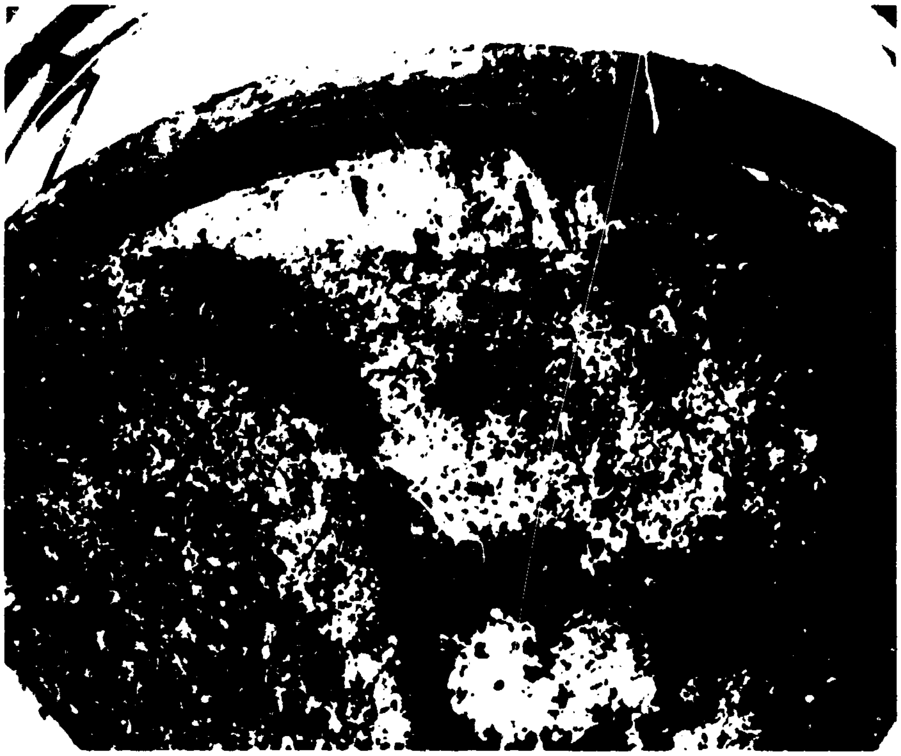

Figure 8. Coating damage on cone of System 12 buoy.

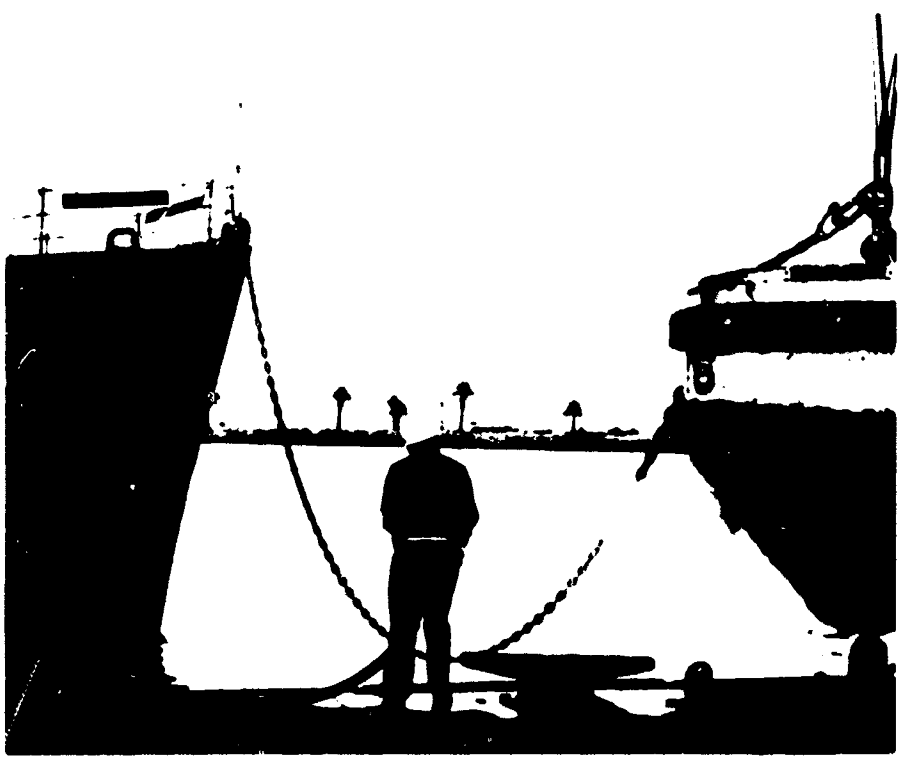

Figure 9. Hosing of System 13C buoy with destroyer secured to it.

Table 3. Overall Ratings of Coated Panels After 4 Years

Coating System		Rating[1]	
Number	Description	Port Hueneme	San Diego
1	Urethane	8	9
2	Epoxy	10	10
3	Epoxy-Polyester	9	9
4	Epoxy-Coal Tar Epoxy	10	10
5	Coal Tar Epoxy-Phenolic	9	9
6	Phenolic Mastic	10	10
7C	Phenolic	9	9
8	Phenolic-Alkyd	9	9
9	Vinyl	10	10
10	High-Body Vinyl	—[2]	—[2]
11	Vinyl Mastic	—[2]	—[2]
12	Inorganic Zinc Silicate-Vinyl Mastic	7	7
13	Saran	9	9

1/ 10 = perfect condition; 0 = complete deterioration.
2/ Systems 10 and 11 failed and were removed from the test program.

Coating System 2: Epoxy

Both epoxy-coated panels were receiving excellent protection. The white antifouling paint originally used on these panels had long since been lost,[4-6] but this had not affected the protection afforded by the epoxy system. In order to determine if this system could be used with other, more conventional antifouling paints, two panels were coated with Coating System 2; one was then coated with vinyl antifouling MIL-P-15931A, and the other with a proprietary copper oxide containing polyester antifouling.[7-9] After 2 years of exposure in Port Hueneme Harbor, the antifouling paints were both adhering well to the epoxy coating and were effectively mitigating fouling.

Coating System 3: Epoxy-Polyester

As previously reported,[4-9] when the antifouling paint (identical to that used with System 2) was lost from the System 3 panels, it took the polyester topcoats with it, thus exposing the underlying epoxy primer. This primer has continued to protect the panels at both locations. The slight rusting on both panels was mostly caused by edge damage. There was slight checking in the atmospheric zone of the Port Hueneme panel.

Coating System 4: Epoxy-Coal Tar Epoxy

Neither System 4 panel had shown any deterioration other than slight edge rusting on the San Diego panel.

Coating System 5: Coal Tar Epoxy-Phenolic

On both System 5 panels, the white topcoat had previously been almost completely lost in the tidal and submerged zones,[3-8] exposing the underlying seal coat. The seal coat continued to provide good protection, with the slight rusting present mostly restricted to panel edges. There was slight checking in the atmospheric zone of both panels.

Coating System 6: Phenolic Mastic

The System 6 panels showed no deterioration in any zone at Port Hueneme and only slight edge rusting in the submerged zone at San Diego.

Coating System 7C: Phenolic

The System 7C panels had only slight further deterioration since the last inspection. There was no increase in the number of small blisters previously noted[8] in the submerged zone. Greater amounts of primer continued to be exposed by the gradual erosion of the black antifouling coating, but there continues to be somewhat less fouling on the System 7C panels than on adjacent panels without an antifouling coating (see Table 1 for panels that have antifouling coatings). Slight barnacle damage, however, was noted for the first time on both System 7C panels.

Coating System 8: Phenolic-Alkyd

System 8 is identical to 7C in the tidal and submerged zones; consequently, the conditions of the two coating systems in these areas were similar. The coatings in the atmospheric zones of these systems, though different, were providing relatively good protection.

Coating System 9: Vinyl

Both System 9 panels were free of corrosion. Although the antifouling coating continued to erode away gradually, thus exposing the underlying primer, there continued to be appreciably less fouling on the System 9 panels than on panels without an antifouling coating.

Coating System 10: High-Body Vinyl

Both System 10 panels were previously removed from the test program because of coating failure.

Coating System 11: Vinyl Mastic

Both System 11 panels were previously removed from the test program because of coating failure.

Coating System 12: Inorganic Zinc Silicate-Vinyl Mastic

Both of the System 12 panels had previously lost much of their vinyl mastic topcoating in the tidal and submerged zones. While the inorganic zinc primer thus exposed was initially quite effective in preventing corrosion, there was now extensive rusting and pitting. The System 12 panels were, therefore, removed from the test program at the time of the present inspection.

Coating System 13: Saran

Both System 13 panels were still in relatively good condition. Most of the corrosion present consisted of pinpoint or edge rusting.

CATHODIC PROTECTION RESULTS

The electrical potentials of the three cathodically protected buoys (Systems 6C, 7C, and 13C) at the time of the inspection were -880, -840, and -900 mv, respectively, as compared to a reference silver-silver chloride half-cell. The potential of the 13C buoy was measured with a destroyer secured to it. All potentials were near or above the level of -850 mv, which was considered necessary for complete protection of exposed steel. The average potential of buoys without cathodic protection was about -710 mv.

The appearance of the zinc anodes gave further evidence of the satisfactory performance of the cathodic-protection systems. After the loose, yellowish film was removed during the high-pressure hosing of the buoy fouling, the zinc surfaces were clean and crystalline. The sacrificial anodes had become appreciably reduced in thickness since their original installation 33 months earlier, but there appeared to be sufficient zinc remaining to provide protection for at least another 1/2 year.

The cathodically protected buoys had considerably less rusting underwater than the unprotected control buoys. The foot-square section of bare steel previously exposed by wire brushing[3] on the cone of the System 13C buoy had received excellent protection from rusting. The riser chains of the protected buoys were also in better condition than those of buoys without cathodic protection. There was considerably less corrosion of steel and loss of coal tar coating on the former riser chains, and the rust present was in a thin, uniform layer. The unprotected riser chains had alternate areas of bright and rusted steel, indicating active corrosion. It has previously been shown[12] that some of the protection from cathodically protected buoys is transferred down tight riser chains.

DISCUSSION

The condition of the buoy coating systems at the time of each inspection is summarized in Table 4. It can be seen from this table that only slight further deterioration of coatings had occurred since the last inspection.

At the time of this inspection, only three of the coating systems (Systems 2, 6C, and 13C) on test buoys were rated as good; six (Systems 4, 6, 7, 8, 9, and 13) as good-fair; three (Systems 1, 3, and 5) as fair; one (System 12) as poor; and two of the test buoys (Systems 10 and 11) had previously been removed from the test program because of coating failure. The coating systems generally performed better on test panels than on the buoys, because the latter were subject to impact and abrasion damage during service to the Fleet. Nine of the original thirteen coating systems on test panels are still rated as 9 or 10 at both locations. These include all of the systems rated as good or good-fair on test buoys. The ratings of 9 on test panels were frequently due to edge damage that occurred during handling.

The System 2 (epoxy) buoy is currently the test buoy in the best condition and the only buoy without cathodic protection that was rated good. It should be noted that this is a Mark I buoy with lighter fendering than the Mark II buoys (Systems 4, 6C, 7C, 8, 12, and 13C), and consequently, it has received less protection from impact and abrasion than the Mark II buoys. Although the original antifouling paints were rapidly lost from the System 2 buoy and test panels (as well as on those of System 3), other antifouling coatings have been found to adhere well to this coating system.

The coating system on buoys 6 and 6C (phenolic mastic) has continued to perform well despite appreciable abrasion damage to these buoys during their first 2 years of service. No further appreciable abrasion damage has occurred to these buoys since that time, and the System 6 panels were in excellent condition. This system has also performed well in the steel sheet piling study of Alumbaugh and Brouillette.[13]

System 13C (Saran), which was rated as good, also performed well for Alumbaugh and Brouillette.[13] Saran is very resistant to moisture penetration, but has a tendency to be subject to pinpoint rusting.

Coating Systems 7C (phenolic) and 8 (phenolic-alkyd) were both in relatively good condition on both the test panels and the buoys. With both systems, deterioration above water was mostly due to abrasion, and deterioration below water was due to gradual loss of the antifouling coating. Because of the type of fouling in San Diego Bay and the routine removal of fouling periodically by high-pressure hosing, there is no apparent reduction of freeboard on buoys in San Diego Bay, or any other detrimental effect due to fouling. Thus an antifouling paint is not ordinarily used in San Diego Bay. It should also be noted that the effectiveness of antifouling paints on the test buoys in retarding fouling was greatly diminished after 2 years. The longer life of the antifouling coating on the test panels is probably due to a lower rate of leaching by the weaker water currents in which they are located.

Coating System 9 (vinyl) is another example of a system in relatively good condition where the deterioration below water is associated with the gradual loss of the antifouling coating. The buoy coating might be in much better condition if the system used above water was also used below water.

Coating System	0–6	6–12	12–18	18–24	24–30	30–36	36–42	42–48	48–54	54–60
1		G	G	G	G	G-F	G-F	G-F	G-F	F
2	G	G	G		G, G	G		G	G, G	
3	G	F	F		F, F	F		F	F, F	
4		G	G-F	G-F	G-F	G-F	G-F	G-F	G-F	G-F
5	G	G-F	F	F	F	F		F	F, F	
6	G	G	G		G	G-F	G-F	G-F	G-F	G-F
6C	G	G	G		G, G	G		G	G, G	
7C	G	G	G	G	G-F	G-F	G-F	G-F	G-F	
8	E	G	G	G, G-F		G-F	G-F	G-F		
9	E	E	G	G	G	G	G-F	G-F	G-F	
10	G	F	F	F	F	P2/				
11		P	P	P2/						
12		F	F	F	F	F	F	F-P	F-P	P2/
13	G	G-F	G-F	G-F	G-F	G-F	G-F		G-F, G-F	
13C	G	G	G		G, G		G	G	G	G

Cumulative Time (months)

1/ Ratings:
E = excellent
G = good
F = fair
P = poor

2/ Removed from test after failure.

Table 4. Condition of Buoy Coatings at Time of Each Inspection 1/

Coating System 4 (epoxy-coal tar epoxy) was providing good protection to both the buoy and the panels. Much of the epoxy topcoat and seal coat had been lost from the buoy below water, but this had not occurred on either test panel. Conversely, Coating System 5 (coal tar epoxy-phenolic) had lost much of the phenolic topcoat from the submerged portion of the panels, but this was not occurring on the buoy. The seal coat and underlying coal tar epoxy remaining on the System 5 test panels was continuing to provide good protection to the steel.

Coating System 1 (urethane) buoy and panels had deteriorated somewhat since the previous inspection, but the system is performing satisfactorily.

Coating System 3 (epoxy-polyester) was providing good protection to both the buoy and panels despite the loss of much of the polyester topcoating below water.

The System 12 (inorganic zinc silicate-vinyl mastic) buoy and panels had deteriorated appreciably since the previous inspection and had extensive rusting and pitting. Because of this deterioration they were removed from the test program.

The patches of underwater-curing epoxy applied at various times in the past have continued to provide good protection to steel exposed by abrasion damage to coatings. They have extended greatly the service life of buoys before necessary recoating ashore and have thus resulted in a savings of maintenance funds.

The cathodic protection systems on three of the test buoys have continued to retard corrosion on the underwater portions of these buoys and their riser chains. The zinc anodes providing this protection are relatively inexpensive, costing probably less than $12 annually when prorated over their expected service life.

The wooden fenders on the Mark I buoys are badly damaged and provide relatively little protection from impact and abrasion.

FINDINGS

1. On three of the test buoys, the coating systems were in good condition; six others were rated as good-fair; three as fair; and one as poor. Two buoys had previously been removed from the test program because of coating failure.

2. Two antifouling paints on test panels were still effective after 4 years in appreciably reducing the amount of fouling; on test buoys, the paints had lost their effectiveness after 20 months.

3. Patches of underwater-curing epoxy applied to damaged areas of several different coating systems were quite effective in protecting steel from corrosion below water. Some of these patches have performed well for 4 years.

4. The cathodic protection systems on three of the test buoys were effectively mitigating corrosion. Although the zinc anodes were appreciably reduced in size, they should continue to perform effectively for at least another 1/2 year.

CONCLUSIONS

1. The protective coating systems still under test are giving greater service life to the test mooring buoys than the service life generally received at field activities. Some of the better coating performance is due to better surface preparation and coating application, but much is due to improvements in coating formulations.

2. The use of an antifouling coating on the underwater portion of mooring buoys is not justified unless fouling is known to constitute a maintenance or operational problem.

3. Underwater-curing epoxies can reduce maintenance costs by extending the service life of mooring buoys where localized areas of coating have been damaged by abrasion.

4. Mooring buoys can be effectively cathodically protected underwater with zinc anodes.

RECOMMENDATIONS

1. The coating systems that have performed well to date in the present test should be considered for use by field activities of the Naval Shore Establishment.

2. Underwater-curing epoxies should be carried by field crews inspecting or relocating moorings so that localized areas of damaged coatings can be repaired in place.

3. A greater use should be made of zinc anodes in cathodically protecting Fleet moorings.

4. Treated wood should be used on the lower fenders of Mark I buoys to protect them from marine borer attack.

ACKNOWLEDGMENT

Mr. A. F. Curry of NCEL made an independent rating of the coated buoys and both sets of test panels.

Appendix A

RATINGS OF BUOYS WITH TEST COATINGS

Coating System 1: Urethane

No. of Months in Service: 56

Overall Condition: Fair

Amount of Use: Light

Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	4	4	–
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I1/	8	8	9
Rusting, Type II2/	10	10	10
Fouling, amount	–	H	H
Guano, amount	L	–	–
Structural damage	N	broken fender	dent in steel plate

1/ Without blistering.
2/ With blistering.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 2: Epoxy

No. of Months in Service: 54

Overall Condition: Good

Amount of Use: Heavy

Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	6	6	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	—
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	9	9	9
Rusting, Type II	10	10	10
Fouling, amount	—	M	M
Guano, amount	L	—	—
Structural damage	N	damaged fender	dent in steel plate

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 3: Epoxy–Polyester

No. of Monthes in Service: 54

Overall Condition: Fair

Amount of Use: Heavy

Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	6	6	–
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	5 1/	5 1/
Erosion	10	10	10
Rusting, Type I	9	9	9
Rusting, Type II	10	10	10
Fouling, amount	–	H	H
Guano, amount	H	–	–
Structural damage	fender splintered	damaged fender	fender splintered

1/ Topcoat lost, primer exposed.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 4: Epoxy—Coal Tar Epoxy

No. of Months in Service: 56 | Overall Condition: Good-Fair

Amount of Use: Medium | Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (sculing)	10	10	6[1]
Erosion	10	10	10
Rusting, Type I	9	9	9
Rusting, Type II	10	10	10
Fouling, amount	—	M-H	M-H
Guano, amount	L	—	—
Structural damage	N	N	dent in steel plate

1 Delamination of topcoat and seal coat, exposing coal tar epoxy coating.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 5: Coal Tar Epoxy–Phenolic

No. of Months in Service: 54 Overall Condition: Fair

Amount of Use: Heavy Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	8	8	–
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	1C	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	7 1/	9	9 2/
Rusting, Type II	10	10	10
Fouling, amount	–	H	H
Guano, amount	L	–	–
Structural damage	N	damaged fender	dent in steel plate

1/ Mostly from abrasion of coating by securing assembly.
2/ Rivet heads were badly corroded.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the latter ratings H = heavy, L = light, M = medium and N = none.

Coating System 6: Phenolic Mastic

No. of Months in Service: 54 — Overall Condition: Good-Fair

Amount of Use: Light — Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	8	8	–
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	8 1/	9 1/	9 1/
Rusting, Type II	10	10	10
Fouling, amount	–	H	H
Guano, amount	L	–	–
Structural damage	dent in side; broken fender	damaged fender	dent in steel plate

1/ Mostly from abrasion of coating.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 6C: Phenolic Mastic

No. of Months in Service: 54 — Overall Condition: Good

Amount of Use: Heavy — Type of Mooring: Bow and Stem

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	9 1/	9 1/	9 1/
Rusting, Type II	10	10	10
Fouling, amount	—	L	M
Guano, amount	L	—	—
Structural damage	fender splintered	N	N

1/ Mostly from abrasion of coating.

Note. For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 7C: Phenolic

No. of Months in Service: 49

Overall Condition: Good-Fair

Amount of Use: Heavy

Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	6	6	—
Blistering	N, 10	N, 10	F, 8
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	8 1/
Erosion	10	10	8 1/
Rusting, Type I	9 2/	9 2/	10
Rusting, Type II	10	10	10
Fouling, amount	—	L	L
Guano, amount	L	—	—
Structural damage	N	N	slight dent in steel plate

1/ Mostly antifouling paint.
2/ Mostly from abrasion of coating.

Note. For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 8: Phenolic–Alkyd

No. of Months in Service: 49 | Overall Condition: Good-Fair

Amount of Use: Heavy | Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	M, 6
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	8 1/
Erosion	10	10	8 1/
Rusting, Type I	9 2/	9 2/	9
Rusting, Type II	10	10	9
Fouling, amount	—	L	L-M
Guano, amount	L	—	—
Structural damage	N	N	N

1/ Mostly antifouling paint.
2/ Mostly from abrasion at coating.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 9: Vinyl

No. of Months in Service: 50

Overall Condition: Good-Fair

Amount of Use: Heavy

Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	10	–
Chalking	8	8	–
Blistering	N, 10	N, 10	N, 10
Checking	N, 10	10	10
Cracking	N, 10	10	10
Flaking (scaling)	N, 10	9 1/	10
Erosion	N, 10	10	9 2/
Rusting, Type I	9	9	9
Rusting, Type II	10	10	10
Fouling, amount	–	M	M
Guano, amount	L	–	–
Structural damage	N	dent in steel plate	dent in steel plate

1/ A small area near one flange.
2/ Antifouling paint only.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 12: Inorganic Zinc Silicate–Vinyl Mastic

No. of Months in Service: 56 | Overall Condition: Poor

Amount of Use: Heavy | Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	–
Chalking	8	8	–
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	5 1/
Erosion	10	10	10
Rusting, Type I	9 2/	9 2/	7
Rusting, Type II	10	10	10
Fouling, amount	–	L	L
Guano, amount	L	–	–
Structural damage	N	N	dent in steel plate

1/ Topcoat only.
2/ Mostly from abrasion of coating.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 13: Saran

No. of Months in Service: 54 Overall Condition: Good-Fair

Amount of Use: Light Type of Mooring: Bow and Stern

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	8 1/	9 2/	9 2/
Rusting, Type II	10	10	9
Fouling, amount	—	3/	3/
Guano, amount	3/	—	—
Structural damage	N	fender splintered; dent in steel plate	N

1/ Mostly from abrasion of coating.
2/ Mostly pinpoint rusting.
3/ No fouling or guano present because buoy had been taken ashore for structural repairs.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Coating System 13C: Saran

No. of Months in Service: 54 | Overall Condition: Good

Amount of Use: Heavy | Type of Mooring: Free-Swinging

Condition Rated	Atmospheric	Splash	Submerged
Color	9	9	—
Chalking	8	8	—
Blistering	N, 10	N, 10	N, 10
Checking	10	10	10
Cracking	10	10	10
Flaking (scaling)	10	10	10
Erosion	10	10	10
Rusting, Type I	9	9 1/	10
Rusting, Type II	10	10	10
Fouling, amount	—	L-M	L-M
Guano, amount	L	—	—
Structural damage	dent in steel plate	dent in steel plate	N

1/ Mostly pinpoint rusting.

Note: For chalking, blistering, checking, cracking, flaking, erosion, and rusting a rating of 10 describes a perfect condition, and a rating of 0 describes a completely deteriorated condition. A topcoat color rating of 10 indicates pure white with no yellowing or discoloration other than rust streaks from uncoated bolts, and 0 indicates a color unacceptable to the U. S. Coast Guard. In the letter ratings, H = heavy, L = light, M = medium and N = none.

Appendix B — RATING OF TEST

Coating System No.	1						2						3		
Exposure Site	PH			SD			PH			SD			PH		
Panel Zone	A 1/	T 2/	S 3/	A	T	S	A	T	S	A	T	S	A	T	S
General Protection	8	7	9	9	9	9	10	10	10	10	10	10	9	10	10
Chalking	2	—	—	— 12/	—	—	8	—	—	—	—	—	8	—	—
Checking	10	10	10	10	10	10	10	10	10	10	10	10	8	10	10
Blistering, size	2	6	10	10	10	10	10	10	10	10	10	10	10	10	10
Blistering, frequency	F	F	N 9/	N	N	N	N	N	N	N	N	N	N	N	N
Flaking	10	7 7/	10	10	10	10	10	10	10	10	10	10	10	2 14/	2 14/
Cracking	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Undercutting	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Rusting, type I	9	8	9 10/	9 13/	9 5/	9 13/	10	10	10	10	10	10	9 10/	9 3/	10
Rusting, type II	9	7	10	10	10	10	10	10	10	10	10	10	10	10	10
Pitting	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Fouling, amount	—	L 8/	L	—	L	M 6/	—	H 11/	M	—	M	M	—	M	L
Fouling, area 4/	—	6	6	—	4	1	—	0	2	—	7	1	—	2	1
1. Plant Area	—	9	9	—	9	9	—	9	9	—	9	9	—	9	9
2. Animal Area	—	7	7	—	4	2	—	1	2	—	8	1	—	2	2
a. Tunicates	—	10	10	—	10	7	—	10	10	—	10	5	—	10	10
b. Barnacles	—	7	9	—	4	9	—	1	9	—	8	9	—	3	8
c. Mussels	—	10	9	—	9	9	—	4	7	—	9	9	—	8	9
d. Bryozoa	—	10	9	—	10	10	—	10	9	—	10	10	—	10	9
e. Hydroids	—	10	9	—	10	10	—	10	8	—	10	10	—	10	9
f. Tube Worms	—	10	9	—	10	5	—	10	9	—	10	5	—	10	9
g. Sponges	—	10	10	—	10	9	—	10	10	—	10	9	—	10	10
Overall Rating	8			9			10			10			9		

1/ A = atmospheric zone
2/ T = tidal zone
3/ S = submerged zone
4/ 0 = 100% fouled; 10 = 0% fouled
5/ Slight barnacle damage
6/ M = medium
7/ Delamination of topcoat on one side of panel
8/ L = light
9/ N = none
10/ Mostly at edge
11/ H = heavy

A

Appendix B — RATING OF TEST PANELS AT PORT HUENEME AND SAN DIEGO

2				3						4						5					
	SD			PH			SD			PH			SD			PH			SD		
S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S
10	10	10	10	9	10	10	9	9	9	10	10	10	9	10	9	9	10	10	9	9	9
—	—	—	—	8	—	—	—	—	—	8	—	—	—	—	—	6	—	—	—	—	—
10	10	10	10	8	10	10	10	10	10	10	10	10	10	10	10	8	10	10	8	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	2	2	10	10	6
N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	F[15/]	F	N	N	F
10	10	10	10	10	2[14/]	2[14/]	10	1[14/]	1[14/]	10	10	10	10	10	10	10	1[16/]	2[16/]	10	0[16/]	0[16/]
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	9[10/]	9[3/]	10	9[10/]	9[10/]	9[10/]	10	10	10	9[10/]	10	9[10/]	9[10/]	9	9	9[10/]	9[10/]	9[10/]
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
M	—	M	M	—	M	L	—	M	M	—	H	M	—	M	M	—	H	M	—	M	M
2	—	7	1	—	2	1	—	5	2	—	1	2	—	5	1	—	1	3	—	7	2
9	—	9	9	—	9	9	—	9	9	—	9	9	—	9	9	—	9	9	—	9	9
2	—	8	1	—	2	2	—	6	3	—	2	3	—	6	2	—	2	3	—	8	2
10	—	10	5	—	10	10	—	10	6	—	10	10	—	10	5	—	10	10	—	8	3
9	—	8	9	—	3	8	—	6	9	—	3	9	—	6	8	—	2	8	—	4	9
7	—	9	9	—	8	9	—	9	9	—	6	7	—	10	9	—	7	9	—	9	9
9	—	10	10	—	10	9	—	10	10	—	10	10	—	10	10	—	10	9	—	10	10
8	—	10	10	—	10	9	—	10	10	—	10	8	—	10	10	—	10	8	—	10	10
9	—	10	5	—	10	9	—	10	5	—	10	9	—	10	10	—	10	9	—	10	10
10	—	10	9	—	10	10	—	9	9	—	10	10	—	10	9	—	10	10	—	9	9
	10			9			9			10			10			9			9		

mination of topcoat on
side of panel
light
= none
tly at edge
= heavy

12/ Impossible to determine chalking on San Diego panels because of extremely high tide at time of inspection
13/ A few pin holes only
14/ Antifouling and topcoat lost exposing primer
15/ F = few

16/ Loss of t
17/ System N
eliminat
18/ D = de
19/ Delamin
exposing

T HUENEME AND SAN DIEGO

4						5						6					
PH			SD			PH			SD			PH			SD		
A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S
10	10	10	9	10	9	9	10	10	9	9	9	10	10	10	10	10	9
8	—	—	—	—	—	6	—	—	—	—	—	8	—	—	—	—	—
10	10	10	10	10	10	8	10	10	8	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	2	2	10	10	6	10	10	10	10	10	10
N	N	N	N	N	N	N	F[15]	F	N	N	F	N	N	N	N	N	N
10	10	10	10	10	10	10	1[16]	2[16]	10	0[16]	0[16]	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	9[10]	10	9[10]	9[10]	9	9	9[10]	9[10]	9[10]	10	10	10	10	10	9[10]
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
—	H	M	—	M	M	—	H	M	—	M	M	—	H	M	—	M	H
—	1	2	—	5	1	—	1	3	—	7	2	—	1	2	—	7	1
—	9	9	—	9	9	—	9	9	—	9	9	—	9	9	—	9	9
—	2	3	—	6	2	—	2	3	—	8	2	—	2	2	—	7	1
—	10	10	—	10	5	—	10	10	—	8	3	—	10	10	—	10	6
—	3	9	—	6	8	—	2	8	—	4	9	—	2	9	—	7	9
—	6	7	—	10	9	—	7	9	—	9	9	—	7	7	—	10	8
—	10	10	—	10	10	—	10	9	—	10	10	—	10	9	—	10	10
—	10	8	—	10	10	—	10	8	—	10	10	—	10	9	—	10	10
—	10	9	—	10	10	—	10	9	—	10	10	—	10	9	—	10	5
—	10	10	—	10	9	—	10	10	—	9	9	—	10	10	—	10	9
10			10			9			9			10			10		

to determine chalking on San Diego
ause of extremely high tide at time
on
holes only
and topcoat lost exposing primer

16/ Loss of topcoat exposing gray seal coat
17/ System Nos. 10 and 11 failed and eliminated from test
18/ D = dense
19/ Delamination of primer and topcoat exposing zinc silicate coating

C

Coating System No.	7C						8						9			
Exposure Site	PH			SD			PH			SD			PH			S
Panel Zone	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A
General Protection	10	10	10	9	8	9	10	10	10	9	9	9	10	10	10	10
Chalking	8	—	—	—	—	—	8	—	—	—	—	—	10	—	—	—
Checking	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Blistering, size	10	6	6	10	6	6	10	6	8	10	6	6	10	10	10	10
Blistering, frequency	N	F	F	N	M	M	N	F	F	N	M	M	N	N	N	N
Flaking	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Cracking	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Undercutting	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Rusting, type I	9	9[5/]	10	9[10/]	8[5/]	9[10/]	9	8[5/]	9	9	9[10/]	9[10/]	10	10	10	10
Rusting, type II	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Pitting	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Fouling, amount	—	L	L	—	L	L	—	L	L	—	M	M	—	L	L	—
Fouling, area	—	2	2	—	2	2	—	8	5	—	5	2	—	4	5	—
1. Plant Area	—	4	3	—	8	9	—	9	9	—	8	9	—	4	5	—
2. Animal Area	—	8	9	—	3	2	—	6	9	—	6	2	—	10	10	—
a. Tunicates	—	10	10	—	10	8	—	10	10	—	10	4	—	10	10	—
b. Barnacles	—	8	9	—	7	9	—	7	9	—	6	9	—	10	10	—
c. Mussels	—	10	9	—	10	9	—	10	9	—	10	9	—	10	10	—
d. Bryozoa	—	10	10	—	10	9	—	10	9	—	10	10	—	10	10	—
e. Hydroids	—	10	10	—	10	10	—	10	9	—	9	8	—	10	10	—
f. Tube Worms	—	10	10	—	10	5	—	10	9	—	10	10	—	10	10	—
g. Sponges	—	10	10	—	10	9	—	10	10	—	10	9	—	10	10	—
Overall Rating	9			9			9			9			10			

1/ A = atmospheric zone
2/ T = tidal zone
3/ S = submerged zone
4/ 0 = 100% fouled; 10 = 0% fouled
5/ Slight barnacle damage
6/ M = medium

7/ Delamination of topcoat on one side of panel
8/ L = light
9/ N = none
10/ Mostly at edge
11/ H = heavy

12/ Impossible to d
on San Diego p
extremely high
inspection
13/ A few pin hole
14/ Antifouling an
primer
15/ F = few

A

	9						12[17]						13					
	PH			SD			PH			SD			PH			SD		
S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S	A	T	S
9	10	10	10	10	10	10	10	10	10	10	6	6	10	9	10	9	9	9
—	10	—	—	—	—	—	8	—	—	—	—	—	8	—	—	—	—	—
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
6	10	10	10	10	10	10	10	2	2	10	10	2	10	10	10	10	10	10
M	N	N	N	N	N	N	N	F	F	N	N	F	N	N	N	N	N	N
10	10	10	10	10	10	10	10	2[19]	4[19]	10	0[19]	2[19]	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
9[10]	10	10	10	10	10	10	10	6	7	10	6	6	10	9	10	9	9	9
10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	9	9	10	8	8	10	10	10	10	10	10
M	—	L	L	—	L	L	—	M	M	—	L	M	—	H	H	—	M	M
2	—	4	5	—	2	2	—	3	3	—	8	3	—	1	2	—	6	1
9	—	4	5	—	9	9	—	9	9	—	9	9	—	9	9	—	9	9
2	—	10	10	—	2	2	—	4	4	—	8	3	—	1	2	—	7	1
4	—	10	10	—	10	9	—	10	10	—	10	8	—	10	10	—	10	8
9	—	10	10	—	2	9	—	7	8	—	8	9	—	2	10	—	7	7
9	—	10	10	—	10	9	—	7	6	—	10	9	—	8	4	—	9	9
10	—	10	10	—	10	10	—	10	9	—	10	10	—	10	9	—	10	9
8	—	10	10	—	10	9	—	10	9	—	10	10	—	10	8	—	10	10
10	—	10	10	—	10	5	—	10	9	—	10	10	—	10	9	—	10	5
9	—	10	10	—	10	9	—	10	10	—	10	9	—	10	10	—	10	8
	10			10			7			7			9			9		

12/ Impossible to determine chalking on San Diego panels because of extremely high tide at time of inspection

13/ A few pin holes only

14/ Antifouling and topcoat lost exposing primer

15/ F = few

16/ Loss of topcoat exposing gray seal coat

17/ System Nos. 10 and 11 failed and eliminated from test

18/ D = dense

19/ Delamination of primer and topcoat exposing zinc silicate coating

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13. ABSTRACT

This is the tenth of a series of reports on the protection of mooring buoys. Thirteen buoys were given their ninth rating (after a maximum of 5 years exposure) for extent of coating deterioration, corrosion of steel, and fouling. Two other buoys had previously been removed from the test program because of advanced deterioration. The coating systems on three of the buoys were in good condition, while those on nine others showed varying degrees of moderate deterioration, and one was in such poor condition that it was also removed from the test program. Two sets of steel panels coated with the different systems used on the buoys were given their eighth rating inspection after 4 years of exposure. One set was exposed in San Diego Bay and the other in Port Hueneme Harbor. The condition of the coatings on both sets of panels was generally better than that of the buoy coating, but there was a general correlation between the conditions of the two test groups. On buoys coated with antifouling paints, no detectable antifouling property remained after 20 months, but on both sets of test panels, two antifouling coatings containing copper oxide were still appreciably reducing fouling after 4 years.

Patches of underwater-curing epoxy applied to buoys where localized damage to the coating had been caused by abrasion were in good condition. Some patches had been providing protection for 4 years.

Three of the buoys were cathodically protected with zinc anodes. The underwater portions of these buoys were receiving protection from corrosion 33 months after anode installation.

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Deterioration						
Corrosion						
Fouling						
Antifouling						
Chalking						
Blistering						
Flaking						
Erosion						